"Range influence factors of electric bikes and other electric vehicles“

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BE-9000 Ghent | Belgium

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General view

Rolling losses are important compared to drag losses around cities with low speed and traffic jams

The weight of most vehicles did increase in the last 30 years, but the tendency is down again.

Aerodynamic drag may be important in two wheel vehicles.

P_{tot} = rolling loss+ drag loss + altitude increase + auxiliaries

Technical [1-7]
Altitude and kinetic energy can be partly recovered in EV
In E-bikes: compromise freewheel or energy recovery
Better electric motors material, transistors.
⇒ **mechanical losses get important for possible improvements in and EV**

ICE car driver:
“**Liter/100km**”
1000 km range
= average in altitude, wind
Many times A-B and B-A

BEV driver:
From “A to B”
“range anxiety”?
Altitude, wind
= more important

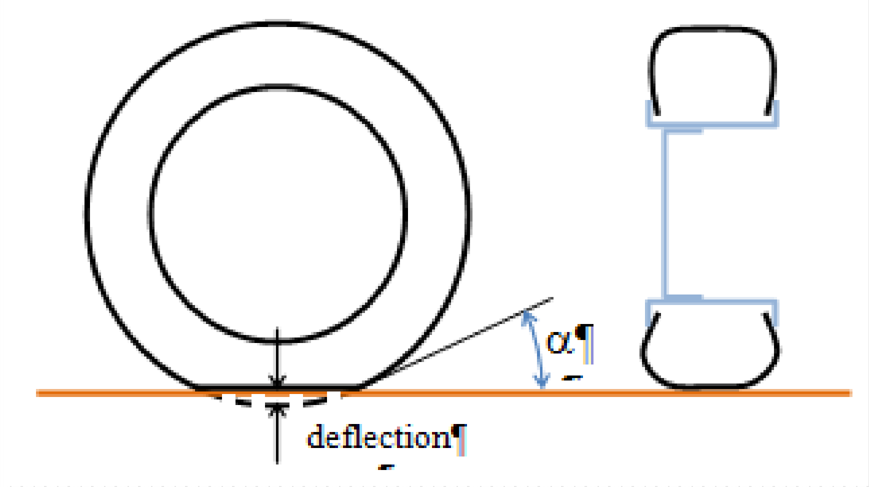
E-biker:
From “A to B”
Need a second battery?
Or a physically heavy end of trip?

Improvements?
Conventional – BEV?

Global:
CO_2, resources

Rolling losses

$$F_R = g\,M\,C_R$$

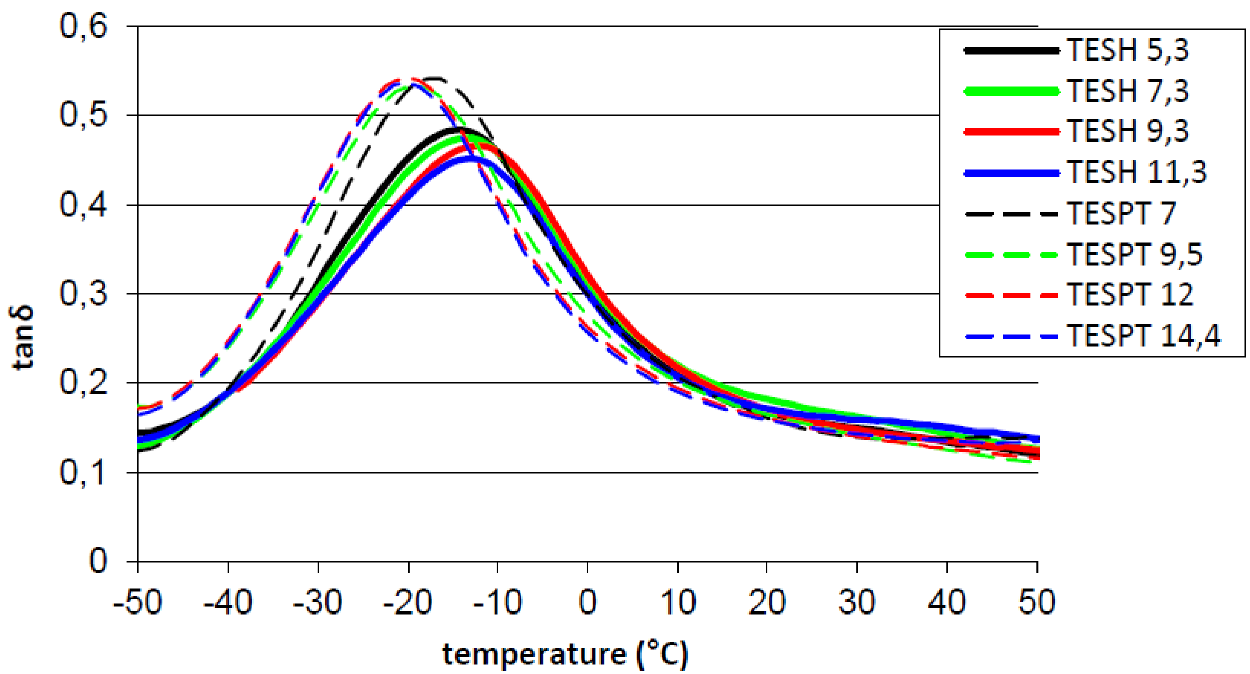


- Side and thread has less losses at high pressure.
- Tread blocks have more losses at high pressure, but less mass in the blocks.
- More losses in a new tire as there is more mass in the tread blocs

The test drum diameter and road type influences the result by the local deflection (only good to compare)

http://www.bicyclerollingresistance.com/tour-reviews/compare

Rolling losses



Reference form the Netherlands [5]
Rubber optimized at lower temperatures <50°

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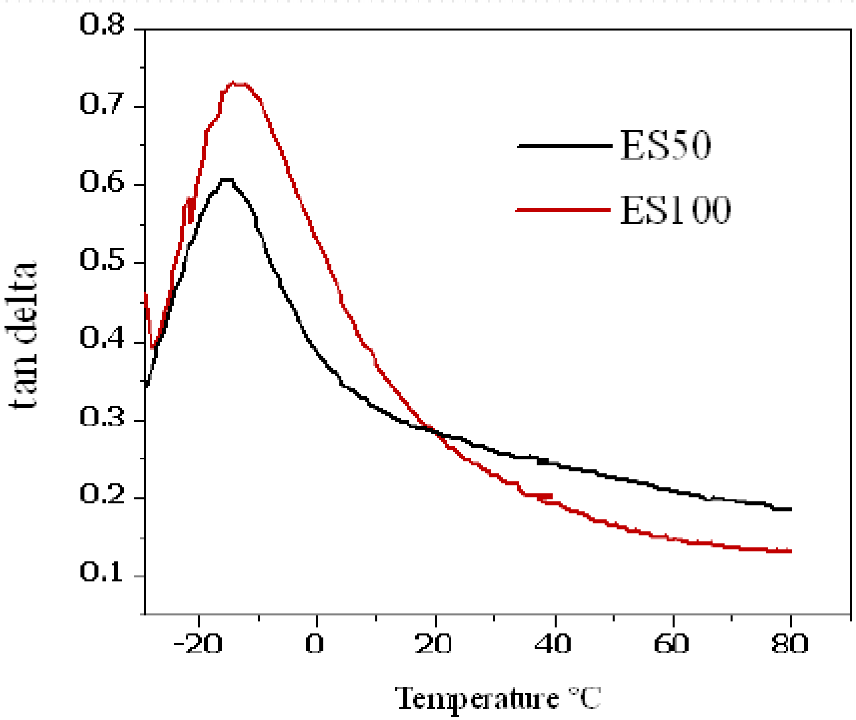
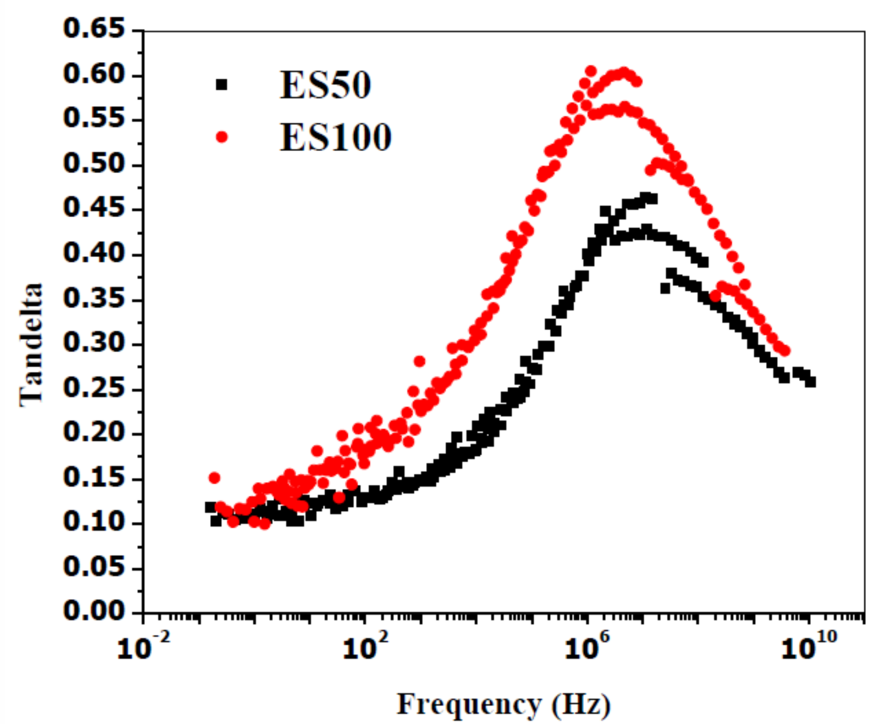
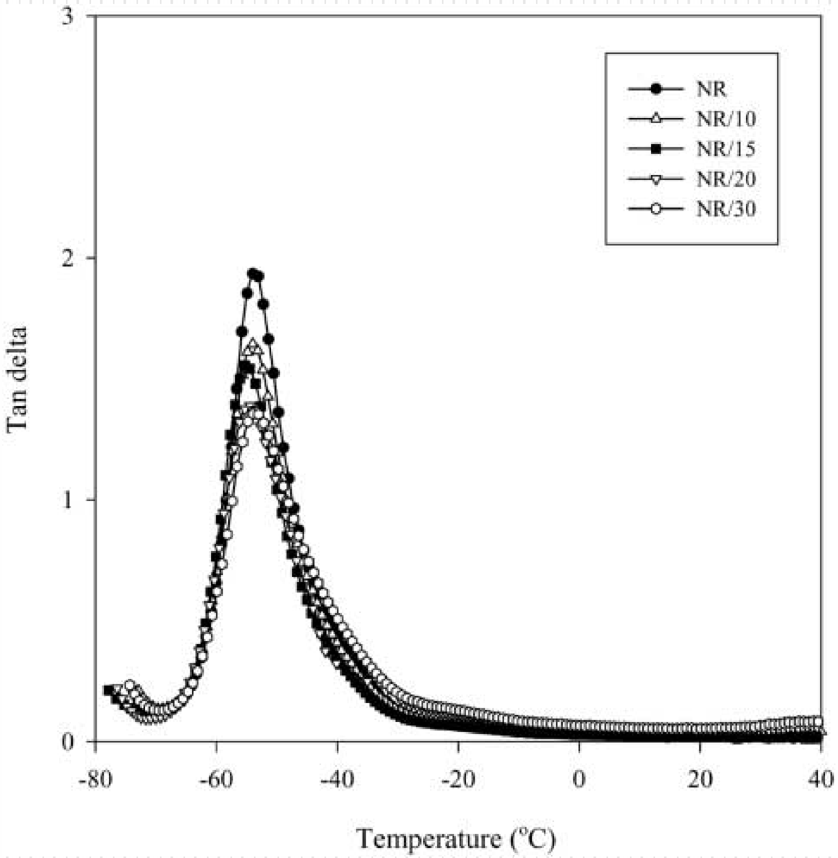
Rolling losses

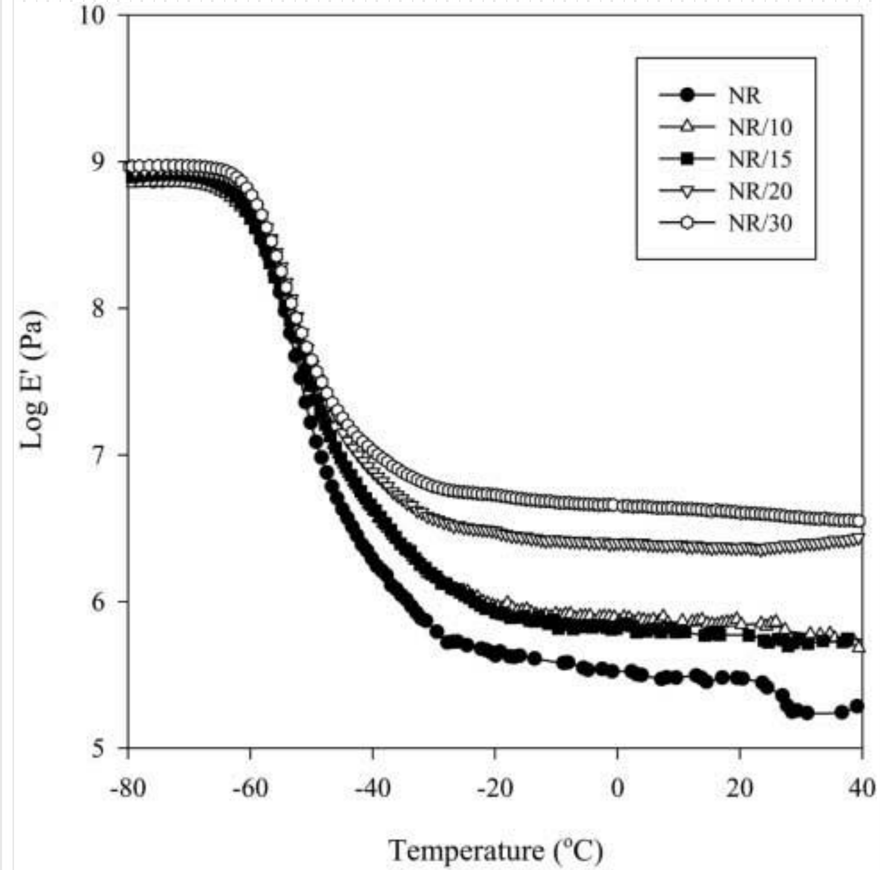




At higher temperatures, source from India [6] , up to 80°C
ES100 contains more silica
Frequency dependence, higher frequencies occur while touching
The region 10^5-10^8 Hz tanδ in beneficial for wet skid performance in tread blocks

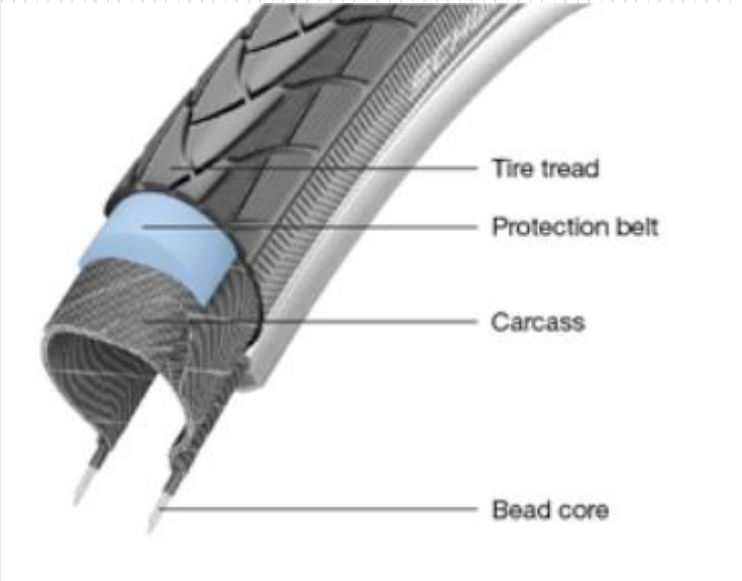
Rolling losses





The pure natural rubber has both a low E-modul and a very low Tan delta, much lower than 0.1
But additives are added to reduce ageing
Ageing Effect on Dynamic and Mechanical Properties of NR/Cel II Nanocomposites

Rolling losses



Schwalbe* : standard tires are equipped with an
effective puncture protection belt made of natural rubber
and
reinforced with Kevlar® fibers (K-Guard)
The protection belt increases the rolling loss, but increases
reliability

*: produced in Indonesia,   Kevlar = aramid fibre,
http://www.schwalbetires.com/tech_info/tire_construction

The density of steel wires makes it
difficult to
Punch trough by the tread
But side walls are vulnerable

Rolling losses

type	Load [kg]	Rolling Coeff.	Speed Limit [km/h]	Diam mm	Press[Bar]	Price €/tire
UC 95/80R16 **Urban concept**	100	0.15%	70	558	5 max	172
Radial 45/75R16 Prototypes tire	100	0.14%	70	478	7 max	172
Type: 44-406 Prototype tyre	-	0.2%		500		58
Grand Prix TT Race bike continental	50	0.297%		622 rim	8.3	50
Truck 40 tonnes	5000	0.8%	130		8	200-800
Car (energy saving)	500	0.7-0.9%	150-250		2.2-2.6	60-100
Normal bike	70	0.7%			3	6-20

Solar race tires do not last long:
One day or half a day
Extreme tires = 1 euro/km?

http://www.design-impact.org/blog/2009/08/extreme-efficiency-secrets-behind-miserly-solar-cars-part-iii-tires/

Extreme rolling coefficient <0.2% is similar to railroad rolling
Energy "label A" tires only for "electric car" and for summer tires…..

http://www.eshopsem.com/boutique/manufacturer.php?id_manufacturer=3
http://www.bicyclerollingresistance.com/road-bike-reviews/continental-grand-prix-tt-2016
https://www.bandenleader.be/auto-band/michelin/energy-e-v

Rolling losses

Australia race a story:

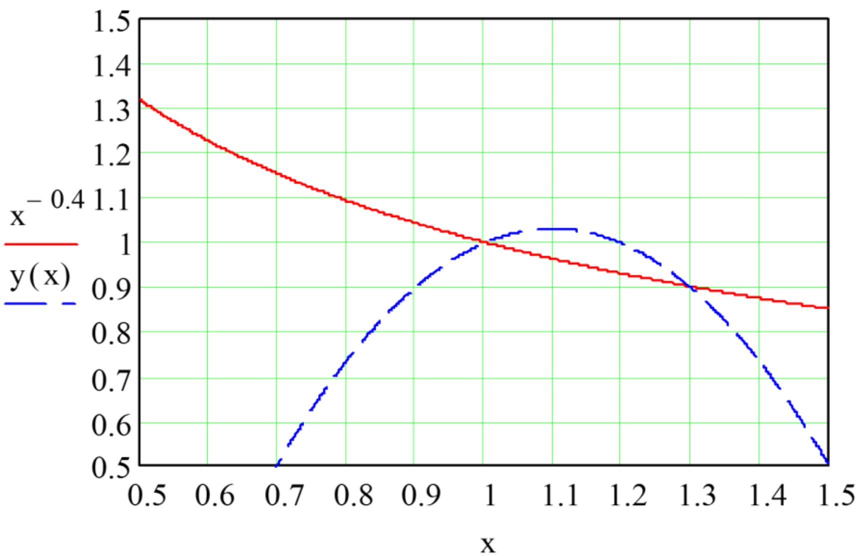
http://www.gizmodo.com.au/2013/06/rubber-to-the-road-why-tyres-are-crucially-important-to-a-solar-car/

“**Rubber To The Road: Why Tyres Are Crucial To A Solar Car”** “Greg Hatten

The solar car gets 16-inch rims,… you could just shove a set of bike tyres on there if you liked, but tyres have a great effect over 3000km and we’ve heard from our little birds that in the last race, they’re what separated the peloton. So instead of doing that, we’re going with bloody expensive, tyres, at €500.
The Michelin Solar Car Radial tyre is 5x less in rolling resistance than a standard energy saving car tyre. That means, the energy it takes to move the car will be 5x less than your little hatchback, though it also means you wear through the tyres incredibly quickly. Over a 7 day race, in the middle of the desert and starting numerous times, you better bet we’d go for the best, Particularly since last year the teams that placed 1st, 2nd and 3rd all used these, accompanied by their million-dollar budgets.

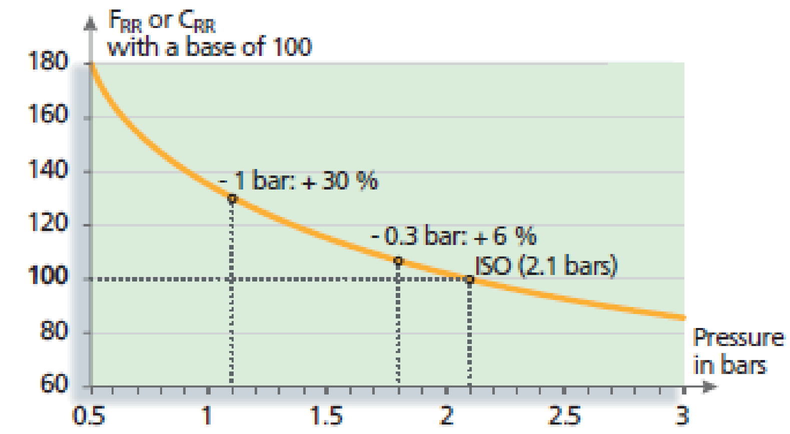
Usually these tyres are incredibly difficult to get your hands on; initially in fact, you could only get these tyres through direct sponsorship from Michelin International in France. We have to thank the UNSW team though, who are on-selling us some they acquired, particularly since usually the limited allocation is reserved for the very best known and best run teams. Once these are attached to our brand new, single disc monocoque carbon fibre rims, also specifically made for this tyre in japan and you’ve got a world beater. Each rim weights about 1.2kg and can support 200kg per wheel. That’s a good thing when the car only weighs 250kg *with* the driver.

Rolling losses

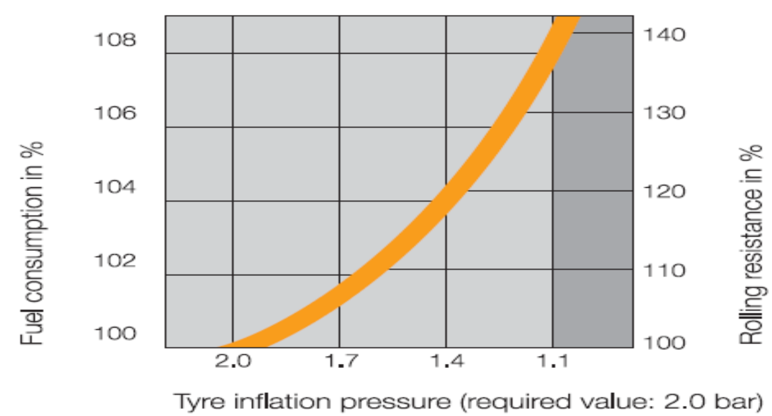


Rolling resistance: red
Lifetime: dashed blue
Depending on relative tire pressure

$$F_R = g\,M\,C_{Rref}\left(\frac{p}{p_{ref}}\right)^{-\alpha} \qquad y(x) = 1.033 - 3.3\left(\frac{p}{p_{ref}} - 1.1\right)^2$$



Michelin [3]



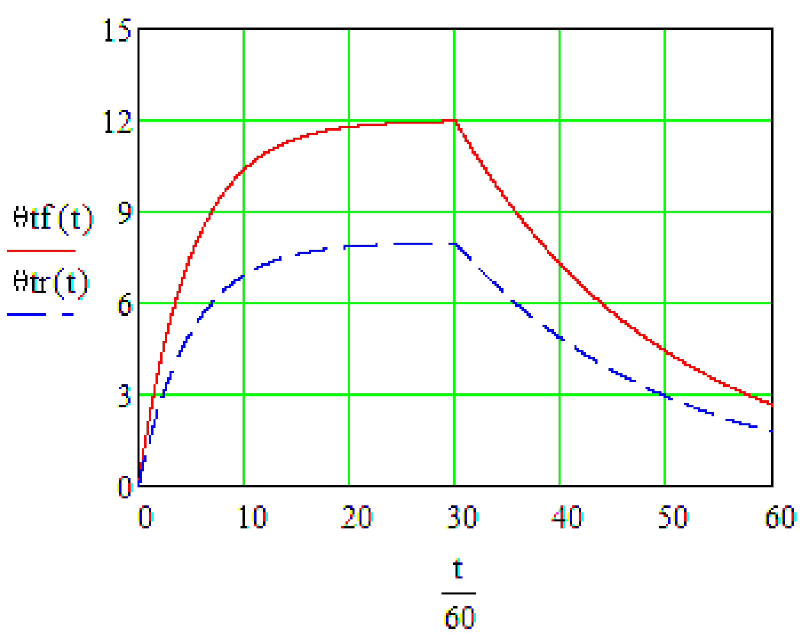
Continental [7]

Rolling losses

Thermal capacity of a car tire: 11.8 kJ/K

Cth = Wr cpr + Wst cpfe
Rubber and iron

Typical thermal resistance of car type
While driving: 0.025K/W.
Standstill: 0.113 K/W
Time constant = Capacity × resistance



Typical tire temperature rise in [K] for:
- front tire θtf (red)
- rear tire θtr (blue, dashed)

For a conventional car (Punto Evo)
30 minute driving
(5 and 20 minute time constants)

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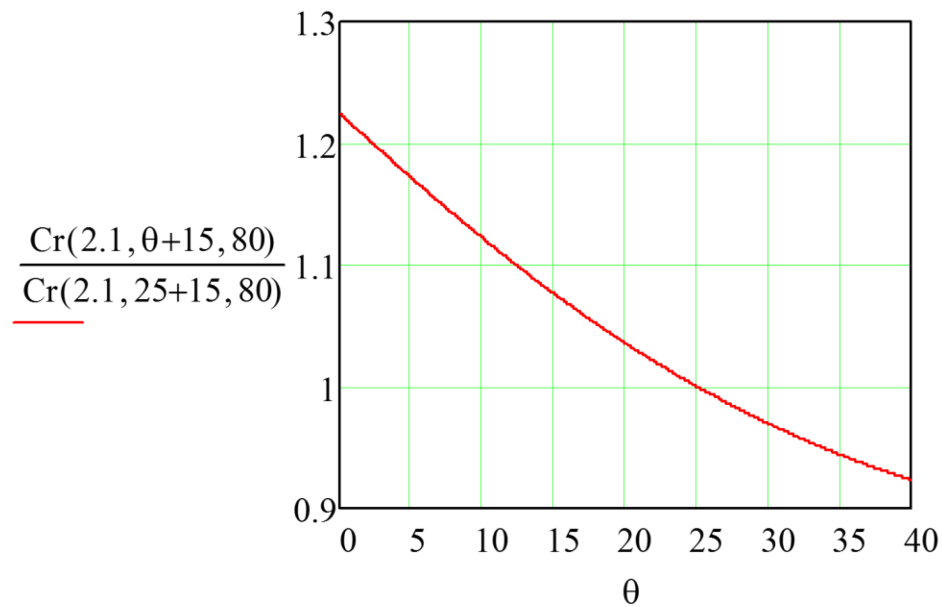
Rolling losses

$$C_R(p,\theta,c) = 0.85\left(\frac{\left(\frac{p}{p_{ref}}\right)^{-0.4}\left(\frac{Z}{Z_{ref}}\right)^{-0.15}}{1+0.35\tanh\left(\frac{\theta-25}{40}\right)}+\left(\frac{c}{500}\right)^2\right)$$

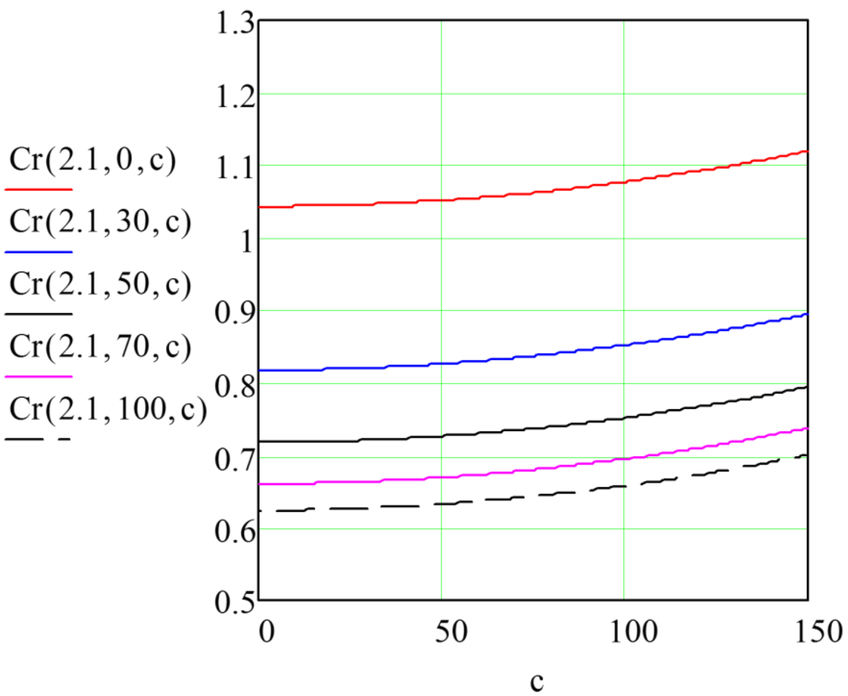


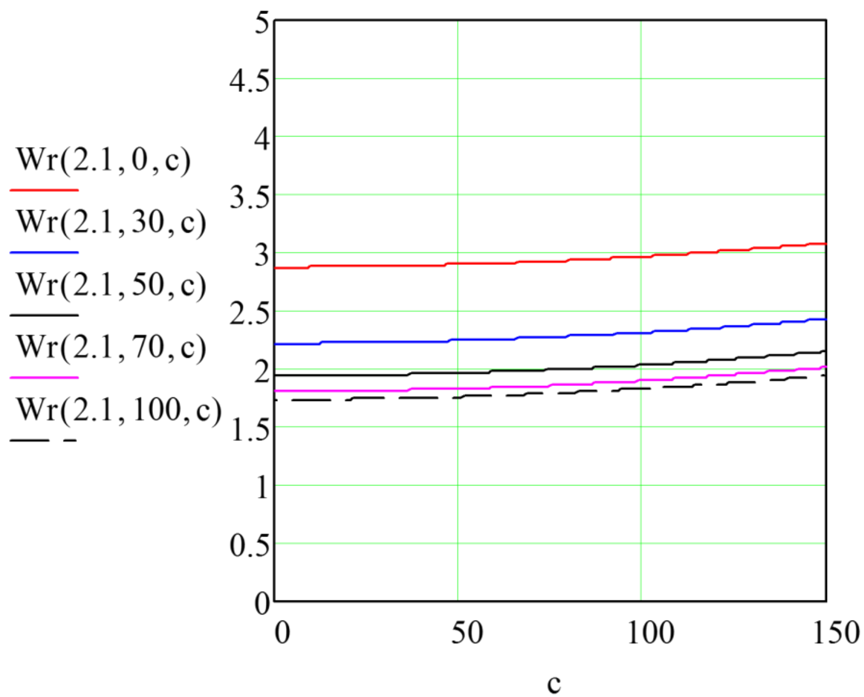
"Collected tire equation":

- p: Pressure
- Z: Load
- θ: tire temperature
- c: speed [km/h]

Effect of ambient temperature
On relative rolling coefficient
At 15K rise compared to ambient

Rolling losses





Effect of tire temperature and speed:

Left: rolling coefficient [%] Right: consumption [kWh/100km]

For $p=p_{ref}$ and $Z=Z_{ref}$

1000 kg vehicle

Divide by 10 for bike

≈ 200 Wh/ 100km?

$$C_R(p,\theta,c) = 0.85\left(\frac{\left(\frac{p}{p_{ref}}\right)^{-0.4}\left(\frac{Z}{Z_{ref}}\right)^{-0.15}}{1+0.35\tanh\left(\frac{\theta-25}{40}\right)} + \left(\frac{c}{500}\right)^2\right)$$

Drag & Wind

Drag including local wind

$$Fd(c,c_{wx}) = \frac{1}{2} A\, C_d\ \rho_o \frac{273}{\theta + 273}\left(\frac{c - c_{wx}}{3.6}\right)^2 \frac{10^5}{3.6 \times 10^6}$$

[kWh/100km]

How to improve drag?
Manufacturer:
Design, smooth bottom (perfectly possible in electric), mirrors…
Droplet - Airfoil design
Try to get a beneficial effect from side wind.

User:
- Less open radiator surface at cold temperature: improves drag and warmer gear and motor.
- Flat wheel caps.

Example: C_d=0.3 A=2m^2 ρ_o=1.225 kg/m^3 (sea level 15°C)

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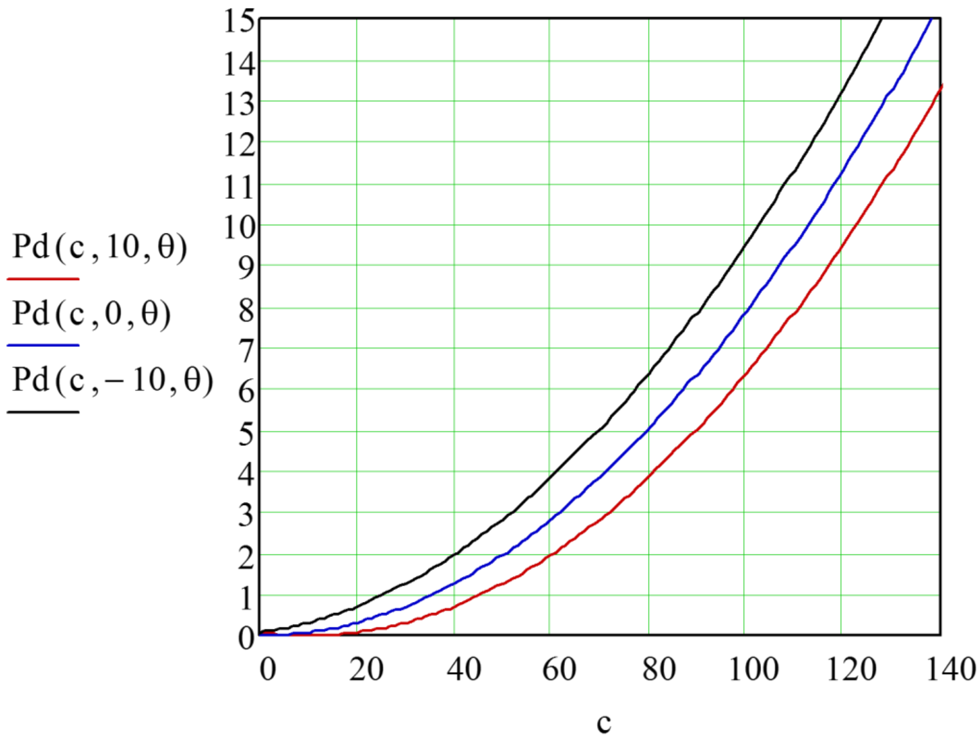
$$Fd(c, c_{wx}) = \frac{1}{2} A\, C_d\ \rho_o \frac{273}{\theta + 273}\left(\frac{c - c_{wx}}{3.6}\right)^2 \frac{10^5}{3.6 \times 10^6}$$

Drag including local wind

Drag
- Without wind
- +10km/h
- -10km/h

A factor 9 at 20km/h =
2.25 more or 4 times less
Look at 60km/h,
Still almost a factor 2!



Basic in kWh/100km depending in on speed for no wind, +10km/h and -10km/h, for Cd=0.3 and A=2.0m² and 15°C]
2 times lower if Cd=0.6 and 0.5 m^2 (bike)
15 times lower if 0.2 m² velomobile Cd=0.2

Drag & Wind

Machine and rider	Drag coeff. on frontal area, cD	Frontal area		CDA	Power to overcome air drag at 10 m/s (22 mi/h) watts	Power to overcome rolling resistance AT 10 m/s for specified total mass, kg, and CR value		
	C_D	m^2	ft^2	m^2	watts	kg.	C_R	watts
Upright commuting bike	1.15	0.55	5.92	0.632	345	90	0.0060	53
Road bike, touring position	1.00	0.40	4.3	0.40	220	95	0.0045	38
Racing bike, rider crouched, tight clothing	0.88	0.36	3.9	0.32	176	81	0.0030	24
Road bike + Zipper fairing	0.52	0.55	5.92	0.29	157	85	0.0045	38
Road bike + pneumatic Aeroshell + bottom skirt	0.21	0.68	7.32	0.14	78.5	90	0.0045	40
Unfaired LWB recumbent (Tour Easy)	0.77	0.35	3.8	0.27	148	90	0.0045	40
Faired LWB recumbent (Avatar Blubell)	0.12	0.48	5.0	0.056	30.8	95	0.0045	42
Vector faired recumbent tricycle, single	0.11	0.42	4.56	0.047	25.8	105	0.0045	46
Road bike in Kyle fairing	0.10	0.71	7.64	0.071	39.0	90	0.0045	40
"M5" faired low racer	0.13	0.35	3.77	0.044	24.2	90	0.003	26
"Flux" SWB, rear fairing	0.55	0.35	3.77	0.194	107	90	0.004	35
Moser bicycle	0.51	0.42	4.52	0.214	118	80	0.003	24
Radius "Peer Gynt" unfaired	0.74	0.56	6.03	0.415	228	90	0.0045	40
"Peer Gynt" + front fairing	0.75	0.58	6.24	0.436	240	93	0.0045	41
ATB (mountain bike)	0.69	0.57	6.14	0.391	215	85	0.0060	50

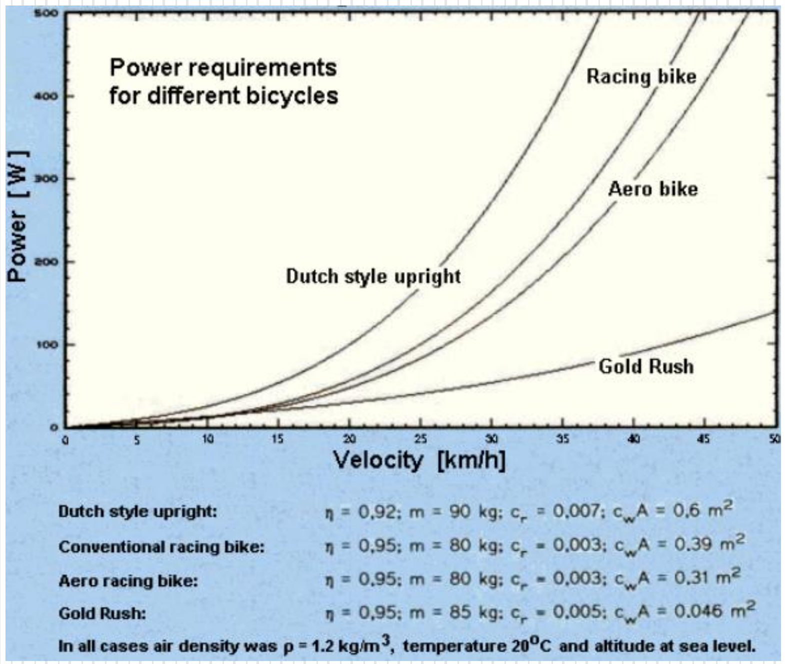
[1] Data from various sources, including Gross, Kyle and Malewicki (1983), and Wilson (1997).

Maximum human speed in velomobile about 132km/h http://www.varnahandcycles.com/records.htm

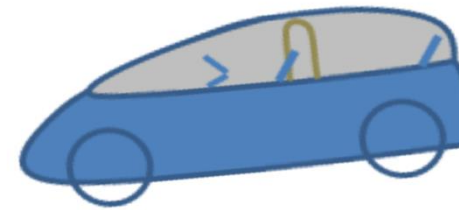
Nice overview from Albert van Dalen
http://www.avdweb.nl/solar-bike/energy-requirements-of-cycling.html

Weight

WAW: human powered 30kg [9]
E-WAW: human+electric assistance 250W, 35kg
www.fietser.be



http://www.sheldonbrown.com/rinard/aero/formulas.htm



Local design for future BEV
2 persons F2E
130kg curb, 90km/h
Improved
"Egg" design [1,2,10]

2.5 kWh/100km
2×5kW peak front drive.
Impact energy absorption

Weight

Power Electronics and drives?

Motor
80-> 93%
Outer rotor,
Thin steel, optimised

Converter
Si-Mosfet -> Ga-N
(Mietec)
Factor 2 in losses:
Both On-resistance and
switching

Gear
Low speed motors
have less efficiency
The gear is optimised
At the same time

Battery?
Better match
BMS charger and
battery
Results in longer life

Battery?
60% of EV cost
Lighter vehicles and
higher efficient drives
need less battery….

Conclusion

- Tire improvements are a compromise with cost and reliability
- Drag improvements are possible, but tend towards velomobile like solutions and pure EV, ultra-light vehicles
- Drive improvements also help to lower the battery cost.

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References

Abstract:
Rolling and drag losses are important in electric vehicles. There is a compromise between price, lifetime, reliability and rolling resistance for tires. In electric bicycles improving the drag would end up in faired bicycles and velomobiles. Still future improvements can be expected from the efficiency of motors, converters and gears.
Improving efficiency reduces the cost of the battery which might be typically 60% of the vehicle cost.

Keywords:
Rolling loss, rubber, temperature coefficient, drag, electric vehicle, electric bikes, ultra-light vehicles.